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FOR

AN AVERAGE CURRENT ESTIMATION SCHEME FOR SWITCHING MODE POWER SUPPLIES

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AN AVERAGE CURRENT ESTIMATION SCHEME FOR SWITCHING MODE POWER SUPPLIES

RELATED APPLICATIONS

The present invention is based on Provisional Serial No. 60/334,849 filed on October 31, 2001. The content of this application is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to switching mode power supplies (SMPS) and their control and in particular to a means of accurately measuring the output current being delivered to a load. The power supply has a dc current estimation circuit that extracts dc current information from a measured peak current signal.

BACKGROUND OF THE INVENTION

In a dc/dc converter, the output current is often needed in many applications, such as current sharing control, current monitoring, etc. The most frequently used method of obtaining dc output current is to use a current sensing resistor, or current shunt, at the output of the dc/dc converter. The problems associated with the current shunt are two fold. First, a current shunt in the output current path will generate a significant power loss, especially for low output voltage dc/dc converters. Second, to extract usable information from the sensed current signal from a noisy environment, a differential amplifier is often needed to pick up the signal and convert it to a proper level, thus increasing the circuit complexity. Therefore, what is needed in the art is a low loss and simple method of estimating dc output current for a dc/dc converter.

FIG. 1 illustrates a prior art circuit that can be used to obtain the dc output current by sensing the switch current, through either a current shunt or a current sensing transformer. U. S. Patent No. 5,457,620 to Dromgoole provides a general explanation of this circuit. An input voltage **102** is supplied to the power transformer **106**. The power

transformer **106** has a primary winding **108** and a secondary winding **110**. The sensed current signal, which is the voltage **123** across the current shunt 124 is supplied to a load switch **126** in series with a low pass filter made of a resistor **128** and a capacitor **130**. The switch **126** is controlled by the same signal driving the power stage switch **122**. When the current signal is sensed by the current shunt or the current sensing transformer, the switch is on and the sensed current signal is let through the low pass filter. The low pass filter helps convert that pulsed signal into the dc current signal. When the power stage switch is off and the current signal is zero, the switch is turned off and the low pass filter holds the sensed current signal till next switch cycle commences.

Although this is a very simple dc current estimation circuit and works reasonably well for many applications, it does have its drawback. The control switch is a floating drive, i.e., the control voltage is not referenced to the gate and the source if a MOSFET is used to implement the current estimation switch. The drive signal becomes part of the current sensing signal, introducing extra error in the estimated current signal. To eliminate the error, some kind of floating drive circuit is needed, either a gate drive transformer or a high side driver, which will in turn complicate the overall circuit.

SUMMARY OF THE INVENTION

The present invention relates to a switching mode power supply and more specifically to an average current estimation circuit that can be used to provide a signal that is proportional to the output current based on a sensed peak current signal by using either a current shunt or a current sensing transformer. In each embodiment, there is a diode through which the peak current signal is fed to a control switch in series with a resistor. A RC filter is in parallel with the series combination of the switch and the resistor.

Compared with the prior art, the invention offers several extra benefits in addition to provide a dc current signal from a sensed peak current. First, a control switch is referenced to the ground, and therefore provides better current estimation accuracy. No extra error is introduced even without the use of a floating drive as shown in the prior art. Next, the peak current signal is always available regardless of the status of the control switch. By separating the peak and average current signals, the converter can be better controlled and both peak current mode control and current sharing control can be optimized. Last, referencing the peak current and average current signals to the different grounds provides freedom to implement different control schemes.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic of a prior art of the average current estimation circuit for a switch mode power supply using Dromgools patent ;

FIG. 2 shows the basic circuit that estimates dc output current through sensing the power stage switch current;

FIG. 3 illustrates the dc output current estimation circuit when using a current shunt to sense the switch current;

FIGS. 4 and **5** illustrate the dc output current estimation circuit when using a current sensing transformer to sense the switch current;

FIG. 6 shows the dc output current estimation circuit when peak current signal and average current signal are referenced to different grounds; and

FIG. 7 illustrates the use of an op-amp and diode circuit for temperature compensation for the sensed dc current signal.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 2 illustrates a basic circuit **200** that estimates dc output current through sensing the power stage switch current. The basic circuit consists of a diode **204**, a resistor **206** in series with a switch **208**, another resistor **210** and a capacitor **212**. When the sensed peak current **202** is applied to the circuit, the switch **208** turns on. The voltage across the resistor **206** and switch **208**, designated V_S, is the sensed peak current V_{Ipk} less a forward diode voltage drop. Resistor **210** and capacitor **212** form a low pass filter which filters out the voltage ripple of V_S and generates a smooth dc voltage 213 whose value corresponds to the output dc current and is independent of the input voltage provided the magnetizing current of the power transformer is neglected. The diode **204** lets the sensed switch current signal through but prevents the voltage V_S as well as V_{Iavg} from being discharged. The switch **208** is a control switch to adjust the sensed dc current signal to reflect the real dc output current. If the load current is decreased, for example, the in-coming current sensing signal is lower than the sensed dc current signal V_{Iavg}. As a result, V_{Iavg} will be discharged during turn-on of switch **208** through resistors **210** and **206**, and switch **208**, being brought down to the level corresponding to the level of the new dc output current.

For this basic implementation and other circuits described below, a timing diagram is also provided showing the voltage waveforms at different points in the circuit. For example, timing diagram **250** shows the sensed peak current signal that is a pulsed voltage $V_{Ipk.}$ **202**. Switch **208** has a duty cycle as shown by waveform **220**. The voltage across switch **208** and resistor **206**, V_S, is shown by waveform **222**. And V_{IAVG}, the dc voltage signal that is indicative of the output current seen by the load, is shown with waveform **224**. Waveforms **202**, **220**, **222**, and **224** are identical for all embodiments. Further, in each embodiment, the basic circuit **200** will be outlined.

With the basic estimation circuit defined, we can apply this circuit to various topologies to implement dc output current estimation. The first circuit discussed here is a forward converter **300** using a resistor to sense the primary switch current I **302**, as shown in **FIG. 3**. The average current sensing circuit **200** is directly connected to the current sensing resistor **304**. During on time of the primary switch **306** the primary

switch current I is the reflected secondary output inductor current I_{L1}. The current generates a voltage signal V_{Ipk} across the current shunt resistor **304**, which is fed to the average current estimation circuit **200**. At the junction of diode **204**, resistor **210**, and resistor **206** a dc signal V_S is obtained which has a small ripple superimposed unto. This ripple is shown in the timing diagram with waveform **320**. Note that switch **208** is synchronized with switch **306**. After the low pass filter, a smooth voltage V_{Iavg} is obtained across the capacitor **212**.

Now turn attention to the same forward circuit **400** with a current sensing transformer **402** as shown in **FIG. 4.** Since it is identical to that given in **FIG. 3,** the power stage is not shown in **FIG. 4.** Now the primary switch current I **404**, which is the reflected output inductor current I_{L1} during the on time, flows through the current sensing transformer **402**. This current is reflected on the secondary side of the current sensing transformer, part of which flows through diode **406** generating the sensed switch current signal across the burden resistor **408** while the rest of which flows through diode **410** generating V_S. Assuming the same voltage drop on the diodes **406** and **410,** V_S is equal to V_{Ipk}. Again the sensed signal V_S is filtered by the low pass filter, generating a smooth dc current signal V_{Iavg}. Examining the circuit given in **FIG. 4** carefully, it can be seen that the circuit branches containing diode **406** and diode **410** form a current divider, thus the final sensed signals depend on the resistor values of **408**, **412**, **414**, and V_{CR10} and V_{CR11}. To simplify circuit design while maintaining one-to-one mapping relationships between the switch current and the sensed V_{Ipk} as well as between the dc output current and sensed V_{Iavg}, the circuit can be designed such that the values of resistor **412** > resistor **414** >> resistor **408**. The peak current sensing and dc output current sensing are no longer coupled by separating the resistor values this way. In addition, one can choose diode **406** and diode **410** being the same type diode, better yet physically in the same package, and thus the forward voltage drop variations caused by temperature change will increase or decrease in the same direction, thereby eliminating the temperature effect.

FIG. 5 shows another embodiment of the average current estimation circuit **500** when a current sensing transformer **502** is used. Now the average current estimation circuit is connected to the burden resistor **504**, and the V_{Ipk} signal is directly fed to the diode **512** yielding a dc output current signal. The control of the switch **514** is identical to

that in **FIG. 4**, and the result is the same except that V_S is one diode voltage drop lower than V_{Ipk} signal.

In some applications, the sensed dc output current and the peak switch current are referenced to different grounds. A dc/dc converter where peak current protection is implemented on the primary side while the current share control is implemented on the secondary side is a typical example. **FIG. 6** shows the embodiment of this concept. To simplify the drawing, again, the power stage is omitted. Notice the difference of the current sensing transformer **602** from the previous embodiments. The current sensing transformer has two secondary windings, **606** and **608**, one feeding diode **610** to provide a sensed peak current signal, one feeding diode **612** to provide a sensed dc output current signal. Since the current sensing transformer **602** has two secondary sides, the two signals can be referenced to different grounds SGND1 and SGND2. Selection of the circuit parameters such as resistor values can follow the guidelines described above. One can even design the current sensing transformer secondary windings differently so that the peak current signal and the average dc current signal can be flexibly scaled to the levels desired.

FIG. 7 shows an improvement of the embodiment presented in **FIG. 5** where the sensed dc average current V_{Ivg} is one diode voltage drop below the incoming signal V_{Ipk}. Adding an op-amp **702** after the low pass filter provides a possibility to recover this voltage drop. A diode **704** is between the output and the negative input of the op-amp. By choosing the resistor **705** value to be equal to the resistor **714**, the output of op-amp **702** generates a signal $V_{Iavg.}$ which excludes the voltage drop of diode **706**.

In summary, the present invention provides several benefits in addition to providing a dc current from a sensed peak current. First, the control switch is referenced to the ground, and therefore floating drive for the series switch in the prior art **FIG. 1** is not necessary. Second, the peak current signal is always available regardless of the status of the control switch. By separating the peak and average current signals, the converter can be better controlled and both peak current mode control and current sharing control can be optimized. Third, referencing the peak current and average current signals to the different grounds provides freedom to implement different control schemes.

In the above embodiments, the control switch (e.g., 208 in Fig. 2) is synchronized with the in-coming peak current signal VIpk, i.e., the switch is on when the peak current signal is applied to the current estimation circuit and the switch is off when the peak current is zero. It should be pointed out that the control signal for the switch in the average current estimation circuit can be implemented in different ways, such as inverting, AND, OR or other operations of the power switch(es) control signal(s) depending on how the current sensing is implemented and the topology used.

Although the present invention has been described in detail, those skilled in the art should understand that they can make various changes, substitutions and alterations herein without departing from the spirit and scope of the invention in its broadest form. Indeed, the term "switch mode power supply" is meant to include all topologies with or without transformer isolation. Examples of such variations are implementations of the proposed current sensing scheme to different topologies, such as buck, full bridge, half bridge, or push-pull. A MOSFET is used as the control switch in the above embodiments, other types of active switch such as a bipolar junction transistor is also a viable choice. Slight modification such as exchanging the position of the control switch **Q10** and the resistor **R12** does not change the nature of the circuit and operation principle.